A Particle Swarm Optimization based behavioral and probabilistic fire evacuation model incorporating fire hazards and human behaviors

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Motivation

- Losses attributable to fire in the US in 2004
  - 1,550,500 fires
  - 3,900 deaths
  - 17,785 serious injuries
  - $10 billion in property damage
- Inadequate evacuation enabling infrastructures
- Life Safety Codes are not sufficient to ensure fire safety
- Alternative to prescriptive rules - Performance Based Design

Motivation

- **How do we evaluate the evacuation efficiency of a Performance Based Design?**
  - Large-Scale Evacuation Drills
    - Expensive
    - Time consuming
    - Dangerous
  - Computer-Based Evacuation Simulation
    - Reduces Design Cycle
    - Incorporates Fire Hazard Model and Human Behaviors
    - Allows designers to do “if-then” Fire Scenarios Analyses
    - Assistance in Performance Based Design

Motivation

- **Current behavioral computer models usually have one or more disadvantages as below:**
  - Divide the floor plan into small grids, the computation is very expensive
  - Unrealistic occupant movement
    - “Chess-board” movement
    - Move sequentially based on some rules
  - Absence of Fire hazard model
  - Incapable of capturing human decision-making and critical human behaviors

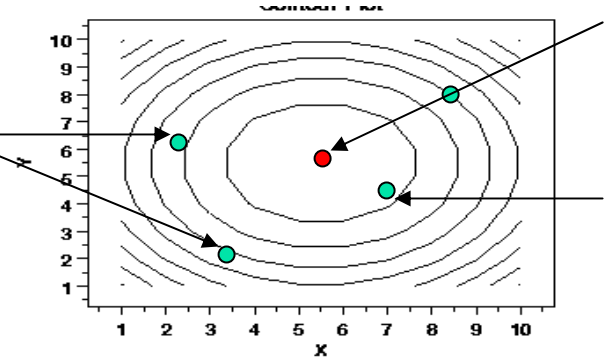
Research Issues

- **Enable coordinate-based occupant movement**
- **Address psychological and physiological human behaviors**
- **Include combined fire hazard effects on human tenability analysis**
- **Incorporate a probabilistic approach to accommodate the uncertainty and complexity of human behaviors**

Background

- **Particle Swarm Optimization (PSO)**
  - Root of PSO ties into artificial life, mainly bird flocking, fish schooling, and swarming theory.

Design solutions analogous to bird in a flock



  - For each particle
    - '*pbest*' - location of the personal best it ever achieved.
    - '*gbest*' - location of the best particle (design solution) in flock.
  - Update Relation

Steering drive from pbest

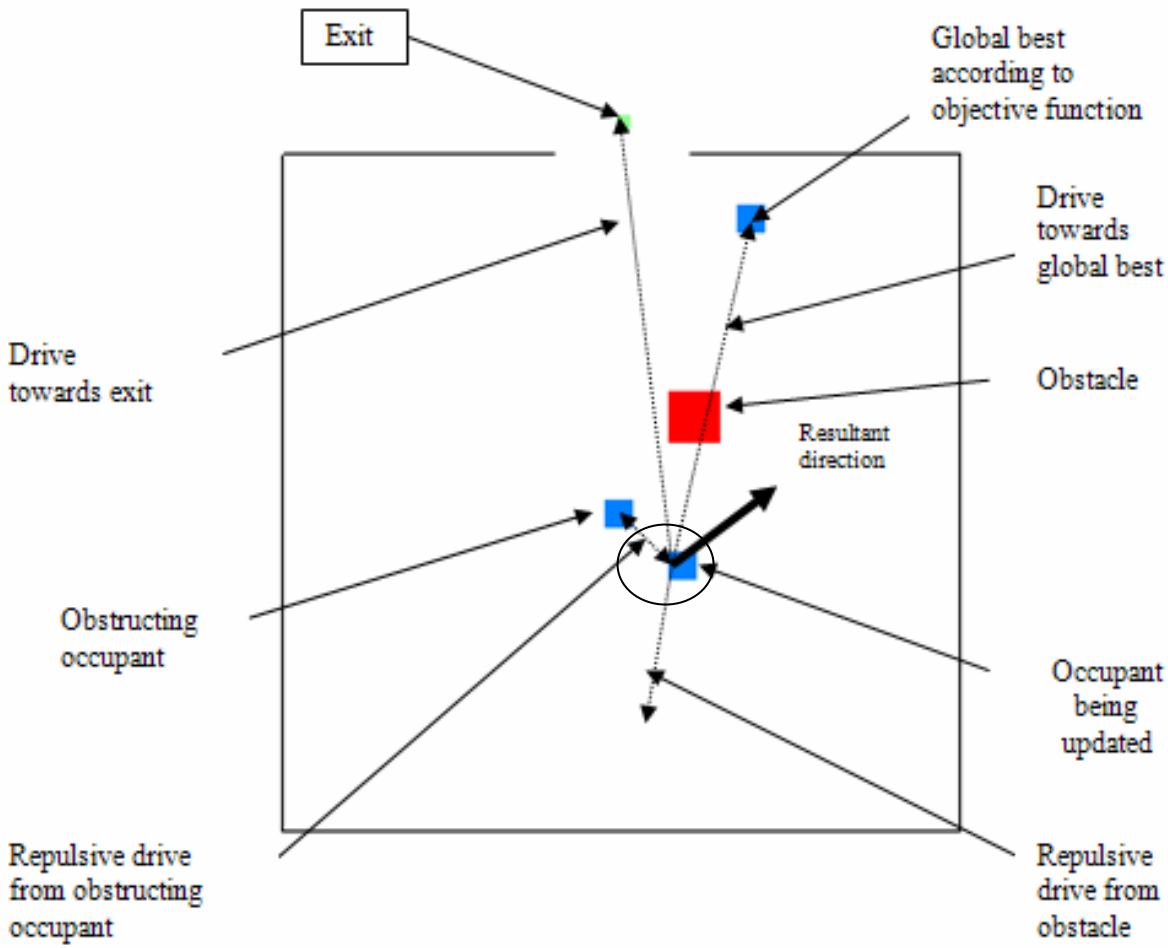
Steering drive from gbest

Velocity $\longrightarrow v = v + c1 * rand() * (pbest - present) + c2 * rand() * (gbest - present)$

Position $\longrightarrow position = position + v$

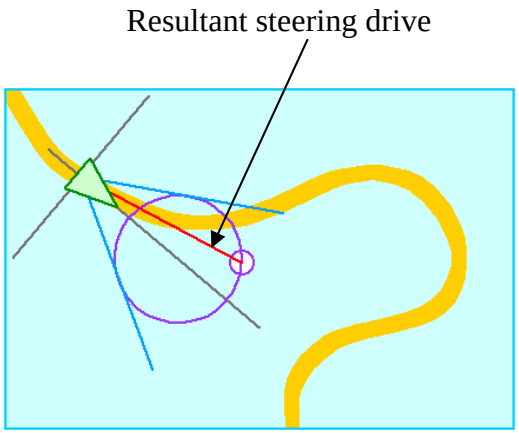
Background

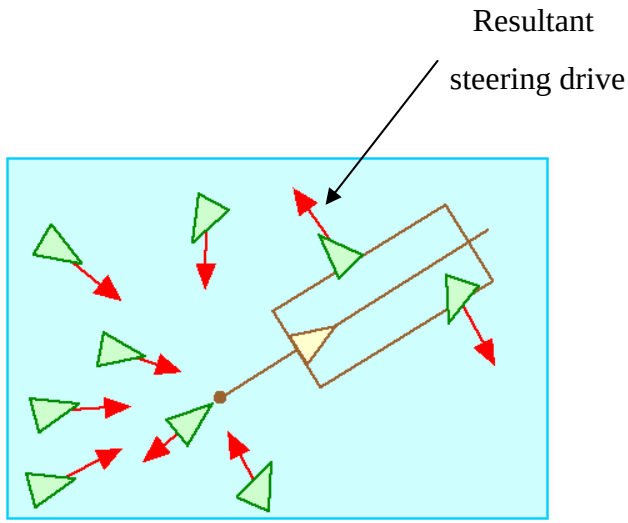
- **Modified PSO**



Background

- **Steering Behaviors used for simulating flocking of birds by Reynolds**
  - Leader following
  - wandering

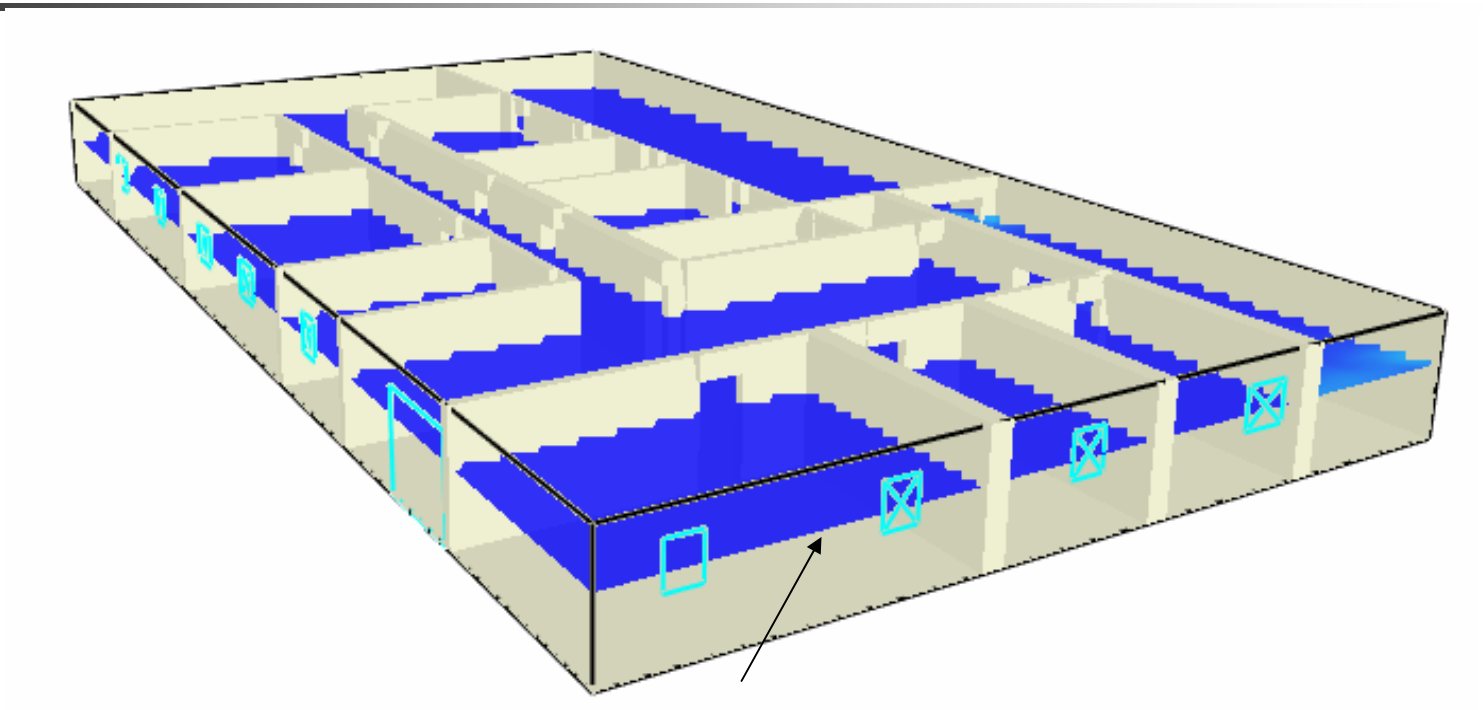




Background

- **Why use PSO as a path-finding algorithm?**
  - Easy to implement
  - Fast due to simple math operators
  - Easy to simulate some complicated behaviors like exploring the space for exit (s) under heavy smoke, follow some occupant adaptively, and etc by just change the weighting factors *Cn*
  - Parallel PSO has good scalability if large scale evacuation needs multi-CPUs

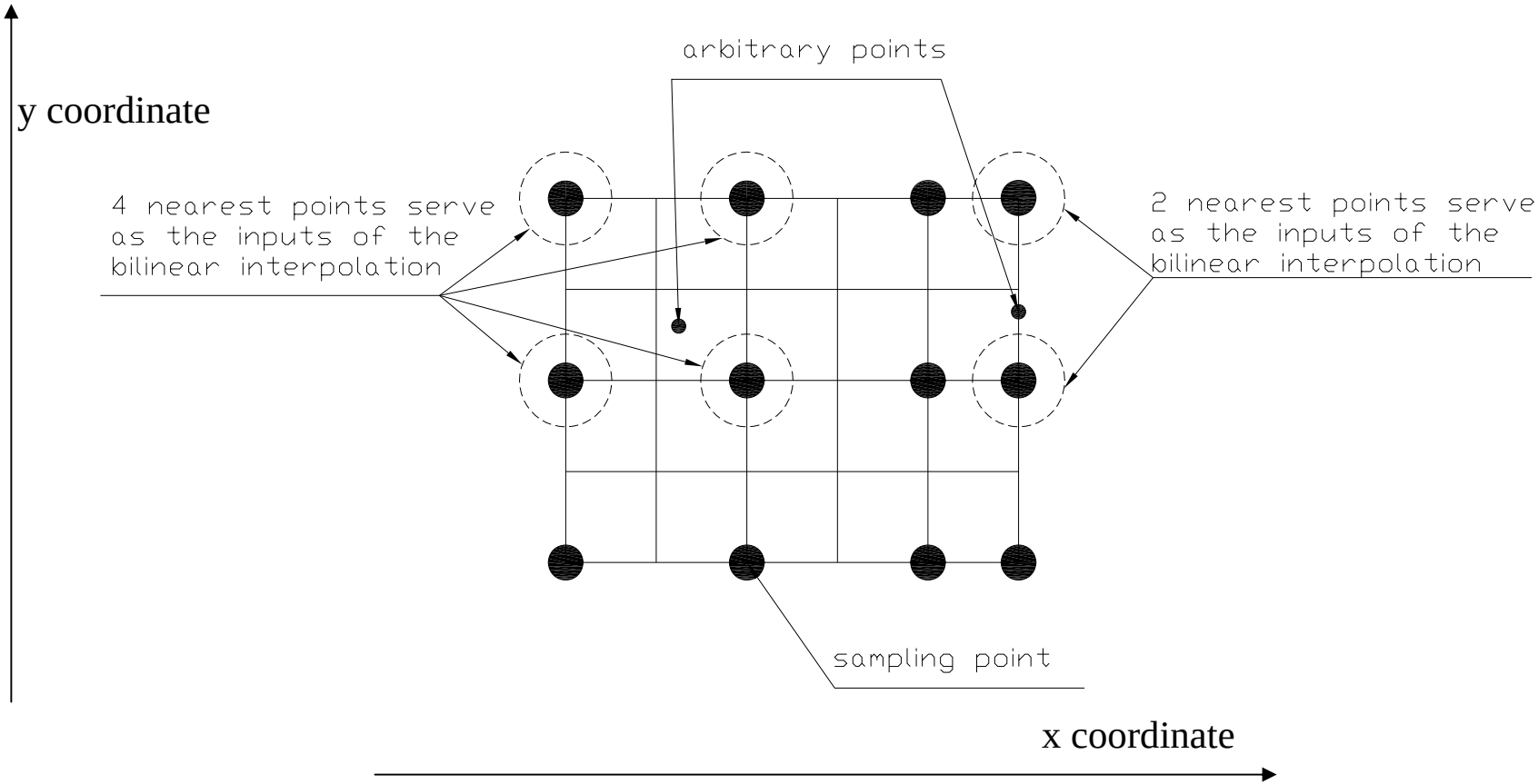
Fire Hazard Model in *Vacate*



Slice file that contains
the fire data (CO, CO2, soot density, and etc) at each time step (pre-calculated in Fire Dynamics Simulators) is inputted in to Vacate

Fire Hazard Model in *Vacate*

Example: Sampling factor =2



Fire Hazard Model in *Vacate*

- **Human tenability analysis in fire hazards**
  - **Using Fractional Effective Dose (FED) Method (Purser)**
  - **Assumption:**
    - **Velocity of occupant decreases linearly with the increase in fire hazards**

FED=1 ⟶ Moving speed =0

FED=0 ⟶ Moving speed = max

  - **FED calculation**

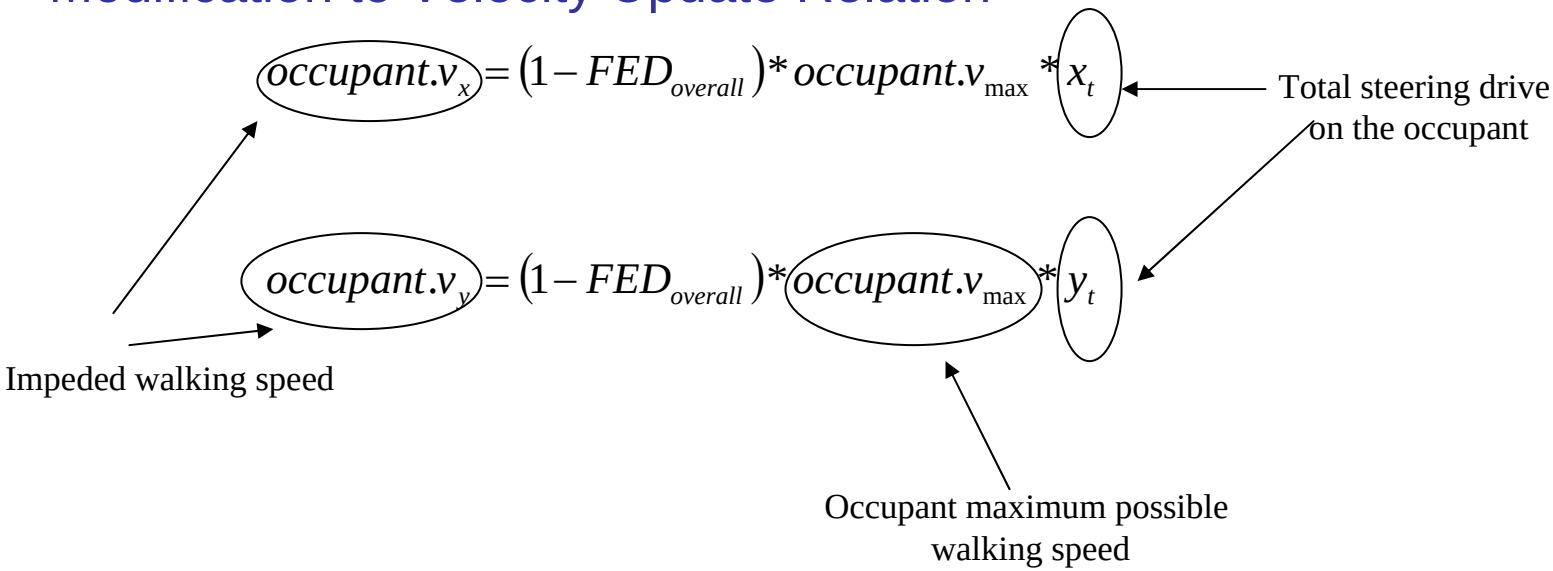
$$FED_{overall} = FED_{rad} + FED_{conv} + FED_{asphy} + FED_{lowOxyH} + FEV_{smoke}$$

Fractional effective visibility

$FED_{overall}$	FED_{rad}	FED_{conv}	FED_{asphy}	$FED_{lowOxyH}$	FEV_{smoke}
Overall FED	Effect of heat radiation	Effect of Heat convection	Effect of Asphyxiant gases	Effect of low oxygen hypoxia	Effect of Smoke obscuration

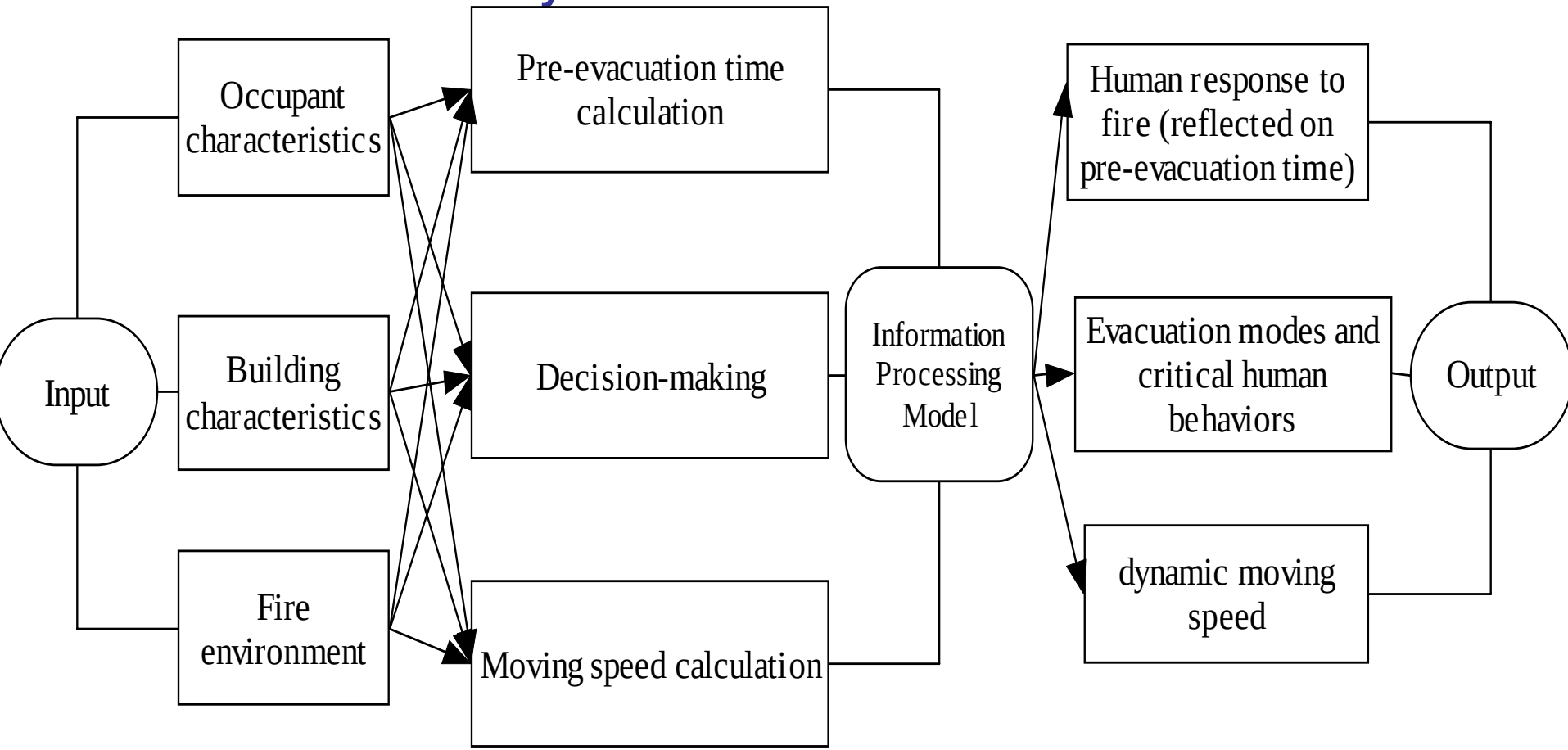
Fire Hazard Model in *Vacate*

- Modification to Velocity Update Relation



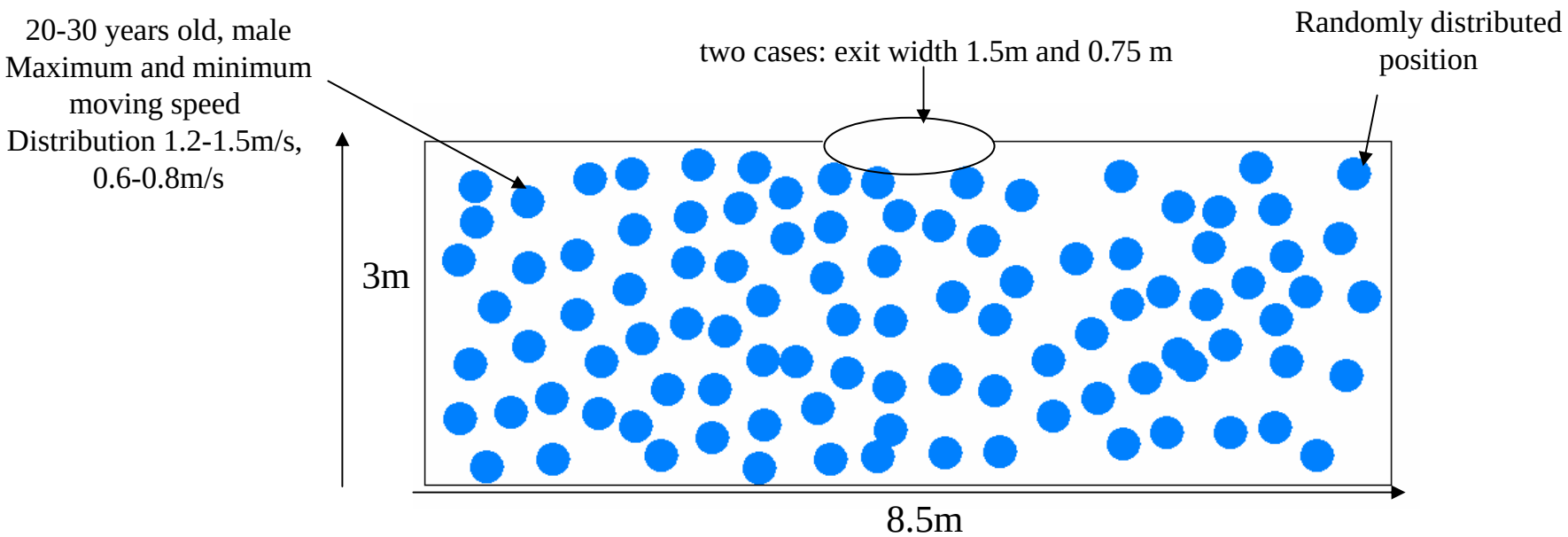
Human Behavior in Fire

- **Human Behavior System**



Validation and Results

- Quantitative validation of *Vacate*
  - Validation data are from an experiment conducted by Stapelfeldt in 1986
  - Demonstrates the evacuation of 100 police cadets from a small room within a school gym



Validation and Results

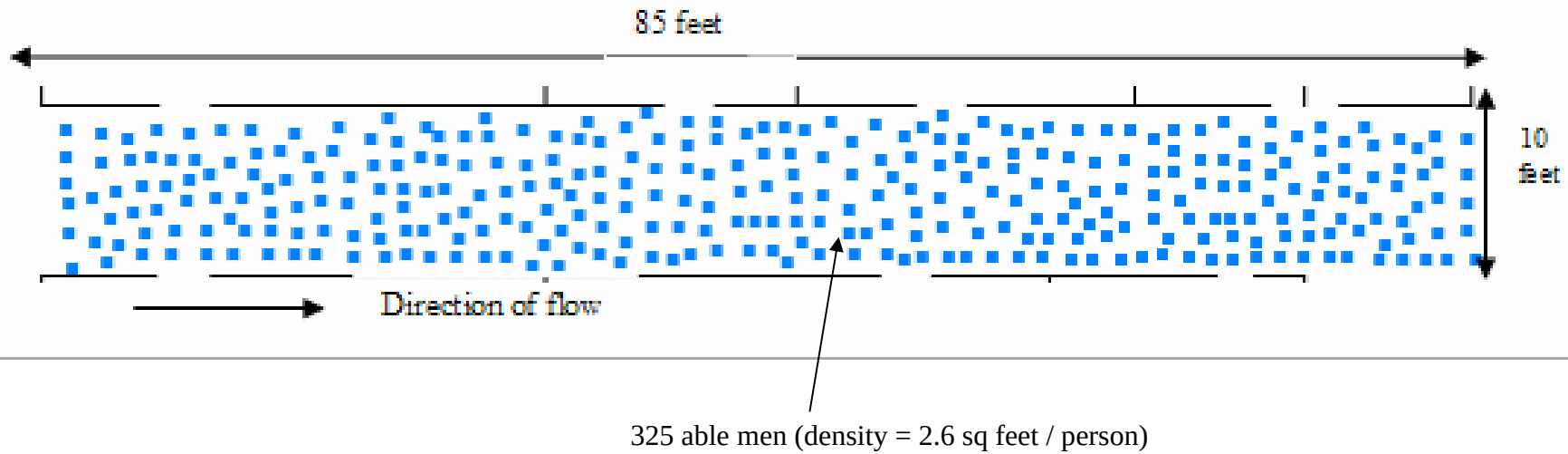
- **Simulation results**

Exit width (m)	Experiment results (sec)	Simulation results from *Vacate (150 runs)* (sec)	Simulation results from *buildingEXODUS** (sec)	Predtechenskii And Milinskii* (sec)	Effective Width Model* (sec)
1.5	30	28.62 [25.60-31.95] (Error: 4.6%)	30.3 [28.8-32.3] (Error: 0.01%)	35-37 (20%)	63 (error: 110%)
0.75	55	48.35 [45.25-51.95] (Error: 12.1%)	51.5 [50.1-53.1] (Error: 6.4%)	69-74 (error:30%)	168 (error: 205.5%)

* **these data are from references**

Validation and results

- Quantitative validation of *Vacate* (case 2, by Gaurav Taygi):
  - Velocity vs. Density Plot



Validation and results

- Velocity vs. Density Plot

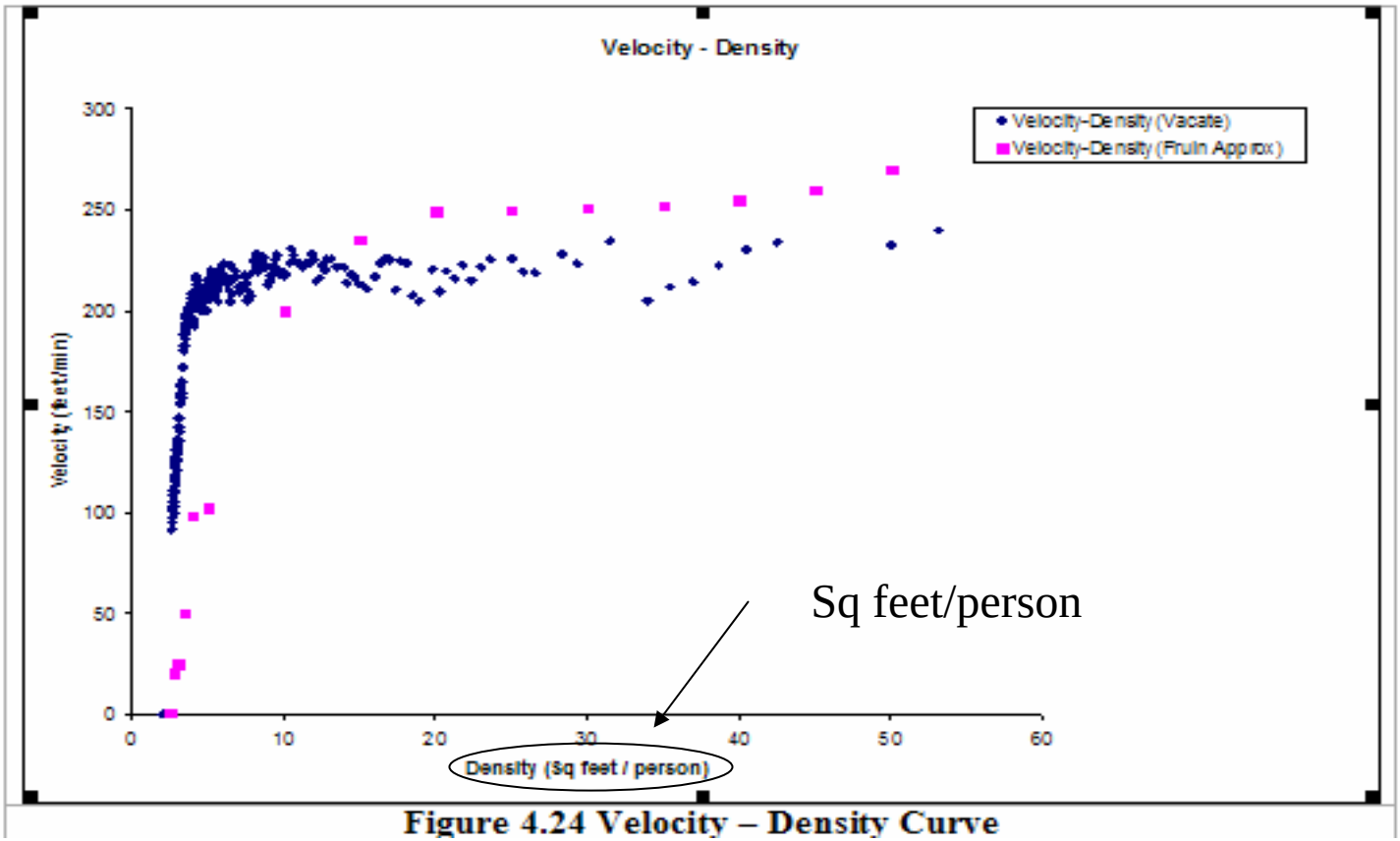


Figure 4.24 Velocity – Density Curve

Validation and Results

- Flow vs. Density Plot

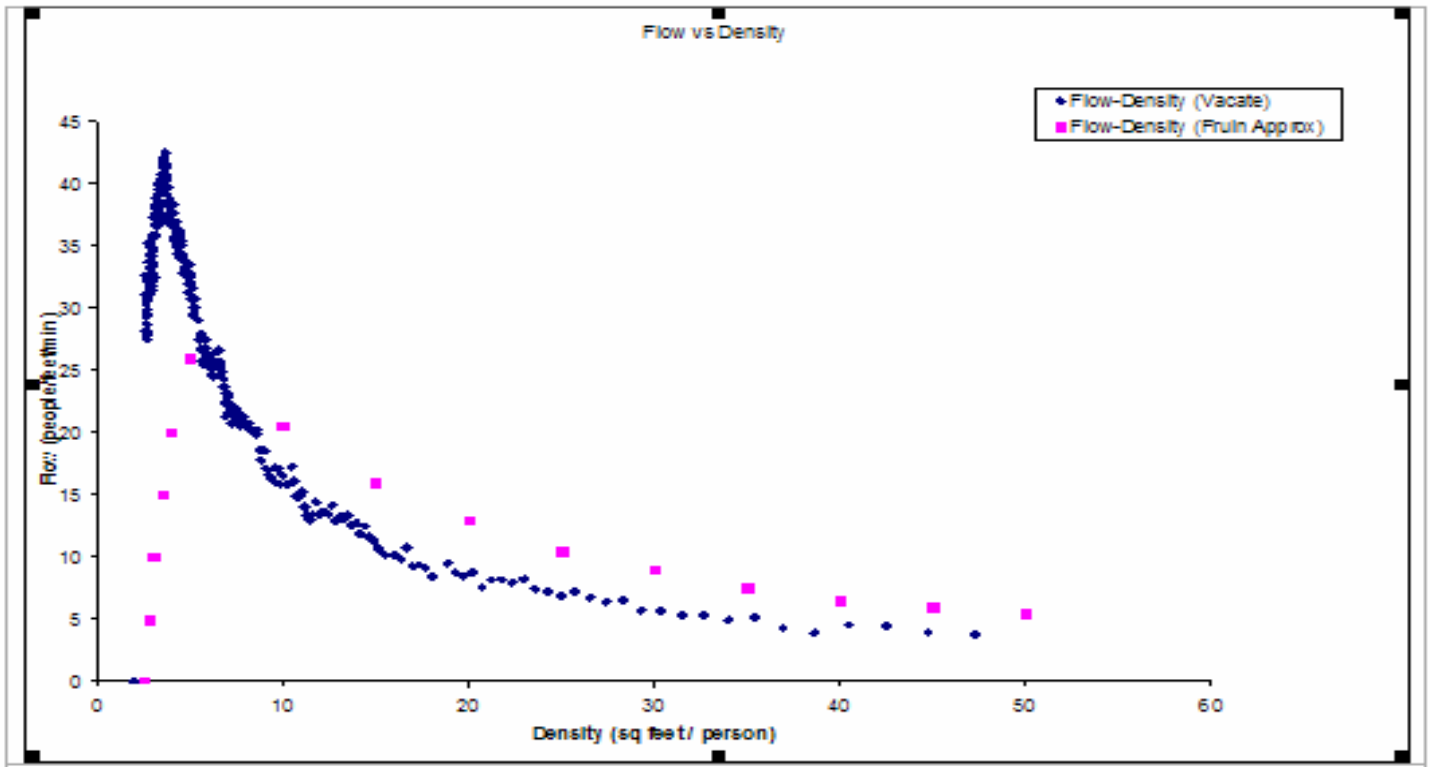


Figure 4.25 Flow – Density Curve

Validation and Results

- **Qualitative testing of *Vacate* (cont.)**
  - Evacuation demo case 1: No fire pools in the floor plan

Validation and Results

- **Qualitative testing of *Vacate* (cont.)**
  - Evacuation demo case 2: with a fire pool in the floor plan

Validation and Results

- **Qualitative testing of *Vacate* (cont.)**
  - Evacuation demo case 3: Multi-floor evacuation

Conclusions

- A PSO-based, probabilistic fire emergency evacuation model, with build-in mini-CAD sketching system
- Coordinate-based movement
- Combined hazard effects of smoke, heat and asphyxiant gases on human tenability assessment
- Introduced probabilistic factors into Information Processing Model to accommodate the uncertainty and unclearness inhuman information processing in emergencies
- Quantitative validation against published data
- Vacate enables engineers to test fire safety design of floor plans

Future work

- Large-scale evacuation involving outside-door and vehicle Evacuation in other emergencies
- Include more complex human behaviors such as looking for loved ones, pushing, falling, trampling and etc.
- Investigate more on the relationship between combined fire hazard effects of smoke, heat and asphyxiant gases and moving speed
- More extensive validation on *Vacate* using validation data with fire hazards from history event

Thank you! ☺

Questions?